A Discussion of Muon-induced Spallation Products from ^{16}O and Their Effects on the SNO Detector

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In the Sudbury Neutrino Observatory (SNO) detector high-energy atmospheric muons can induce spallation in the ^{16}O nuclei in the water, producing free neutrons and other nuclei, some of which are radioactive with substantial lifetimes. Thus, the study of muon-induced spallation products is important since they are a source of neutron and radioactive backgrounds in the SNO detector.

The radioactive decays are problematic only if they produce beta and/or gamma rays above the detector threshold (around 4 MeV). Free neutrons of any energy in the heavy water can be detected. Neutrons typically will randomly walk some distance before capturing on deuterium to produce a 6.5 MeV gamma. Monte Carlo simulations of neutron capture in heavy water have been conducted. These show that the lifetime of the neutron before capture is approximately 40 ms, and during this time the neutrons travel an average distance of approximately 2 meters, with little dependance on the initial neutron energy.

We are mainly concerned with the spallation nuclei and free neutrons that could be produced by a muon striking ^{16}O in the heavy water. Although some research has been done on the oxygen spallation cross sections [1], very little is known about the production cross sections for the unstable nuclei of interest here. So, we must consider all of the possible unstable nuclei that could be produced, i.e. all unstable nuclei with a mass number less than 16 that are likely to be produced by fragmentation of oxygen. Also, although it is not strictly a spallation process, muons can capture on $^{16}_{8}$O and an inverse beta decay process can produce $^{16}_{7}$N and a muon neutrino.

Based on all of the possible radioactive nuclei given in [2], we can identify those that will be the most problematic for the SNO detector. Since neutrons can wander an average of 2 meters before a gamma is emitted, nuclei that decay by neutron emission can be very difficult to correlate spatially with a previous muon track. The longest lived neutron emitting isotope, $^{9}_{3}$Li, has a half-life of 0.178 s. Among the nuclei that do not emit neutrons, the longest lived nuclei are $^{16}_{7}$N, $^{11}_{4}$Be, and $^{10}_{6}$C, with half-lives of 7.13 s, 13.8 s, and 19.255 s respectively.

These half-lives suggest that beta and/or gamma emission, with an energy above 3 MeV, might be observed in the minute following a muon passage. Since the longest-lived isotopes do not emit neutrons, the beta/gamma emission in the later part of this time window should be spatially correlated with the muon track. So, if the fitter resolution is good enough, it might be possible to exclude only events within a specified time window and cylindrical volume surrounding a muon track. The muon flux in the SNO detector is only around 3 events per hour. If all events following within a minute of a muon were cut entirely, this would not translate into an enormous decrease in the detector live time.

More research is now underway to observe these spallation products in the SNO data and to determine the actual decay time of spallation events following muons.

References

[1] Webber, W. R. et al. Phys. Rev. C, **41** (1990).

[2] Firestone et al. *Table of Isotopes*, Eighth Edition, John Wiley and Sons, (New York : 1996)